Advanced Gas Reactor Fuel Development and Qualification Program

Overview and planning *FY04, FY05*

Briefing for the AFCI Meeting

Dr. Madeline Feltus

August 27, 2003

AGR Fuel Program Goals

Provide a baseline fuel qualification data set in support of the licensing and operation of the Generation IV Very High Temperature Gas-Cooled Reactor (VHTR). The baseline fuel form is to be demonstrated and qualified for a peak fuel centerline temperature of 1250°C, with a helium outlet temperature of 1000 °C

— and —

Support near-term deployment of an Advanced Gas Reactor for energy production in the United States by reducing market entry risks associated with fuel production and qualification

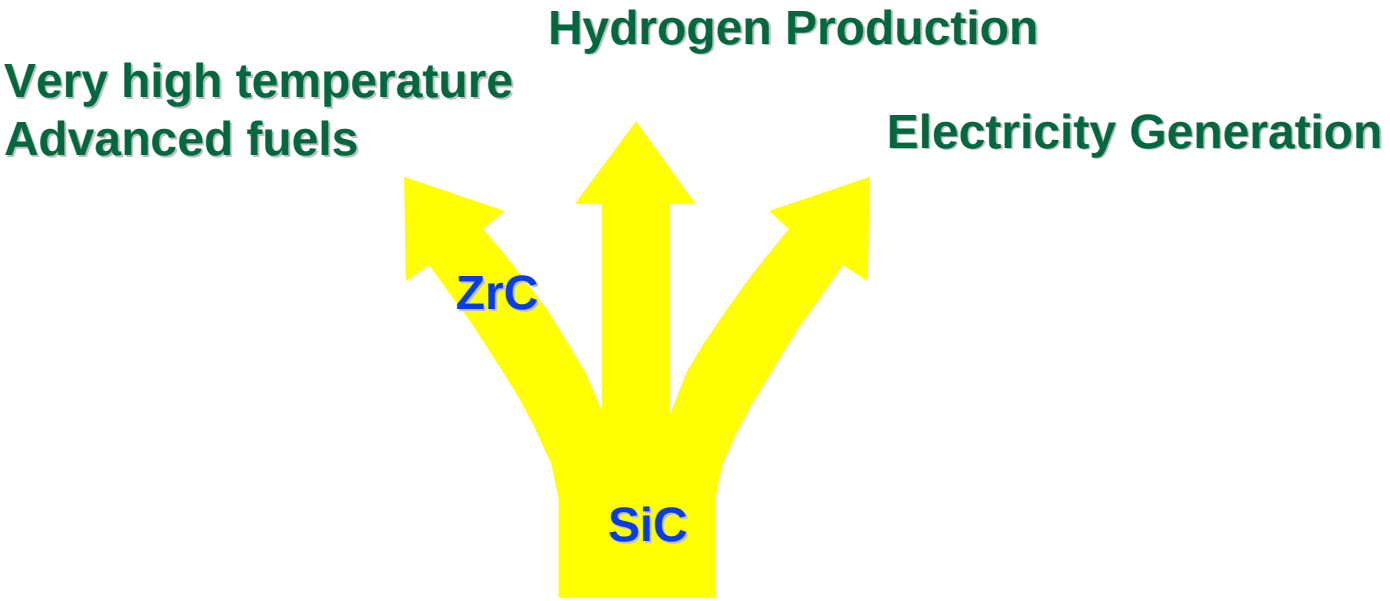
Necessity and Benefits of the AGR Fuel Development and Qualification Program

- **Fuel development and qualification is necessary to deploy an advanced gas reactor design or VHTR**
- **The program**
  - **Addresses one of the key technical risks of future U.S. AGRs**
  - **Establishes a gas reactor TRISO fuel testing program that will support deployment of VHTR, advanced gas-cooled reactors in the U.S.**
  - **Builds the foundation required for U.S. to pursue future advanced gas reactor based applications and advanced fuel R&D**
  - **Provides U.S. with "currency" to leverage international research on gas reactor technology (*EU, France, Japan China, Russia, South Africa*)**

AGR Fuel Program Requirements

- **Manufacture high quality coated fuel particles (LEU with VHTR focus) for irradiation and accident simulation testing**
- **Improve understanding of links between fuel performance, fuel characteristics, and fabrication process parameters**
- **Complete the design and fabrication of multi-cell capsule for ATR irradiation testing of coated particle fuel forms**
- **Demonstrate fuel performance during normal and accident conditions, through irradiation, Safety Testing, and PIE**
- **Improve understanding of fuel behavior and fission product transport to improve predictive fuel performance and fission product transport models, predictive computer codes**
- **Provide data and information needed to support NRC acceptance and licensing**

Program Builds on a Solid Foundation



Peach Bottom	U.S. HTGR Programs (60's, 70's, 80's, 90's)	NPR
German coating process		FSV

TRISO Fuel Development and Qualification - - Needed for NP-2010 and Generation IV, AFCI Programs

R & D
- Fuel particles
- Materials
- He systems technology (850°C)
- Computer codes
- Fuel cycle

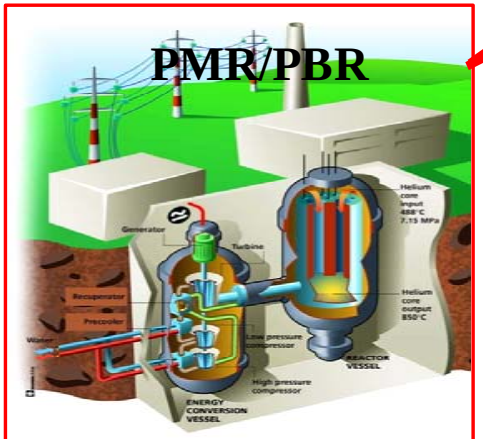
VHTR

GFR

Improved sustainability

> 950°C for VHT heat process

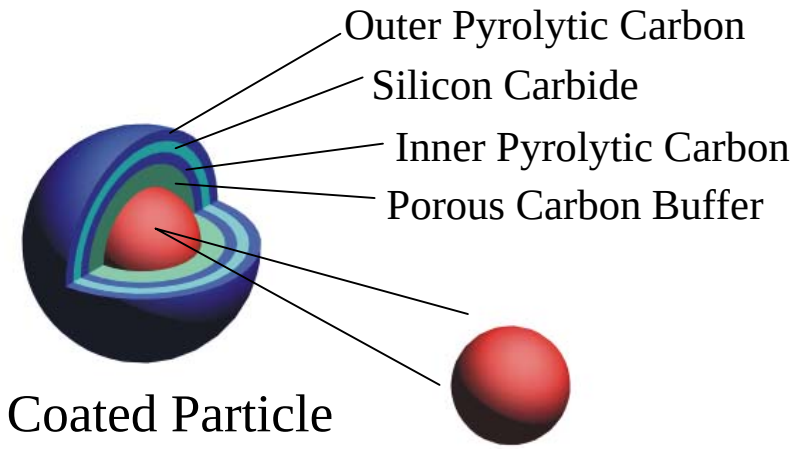
PMR/PBR



R & D
- Fast neutron fuel
- Fuel cycle processes
- Safety systems

R & D
- VHT materials
- IHX for heat process
- ZrC coated fuel
- I-S cycle H2 production

Coated Particle Fuel



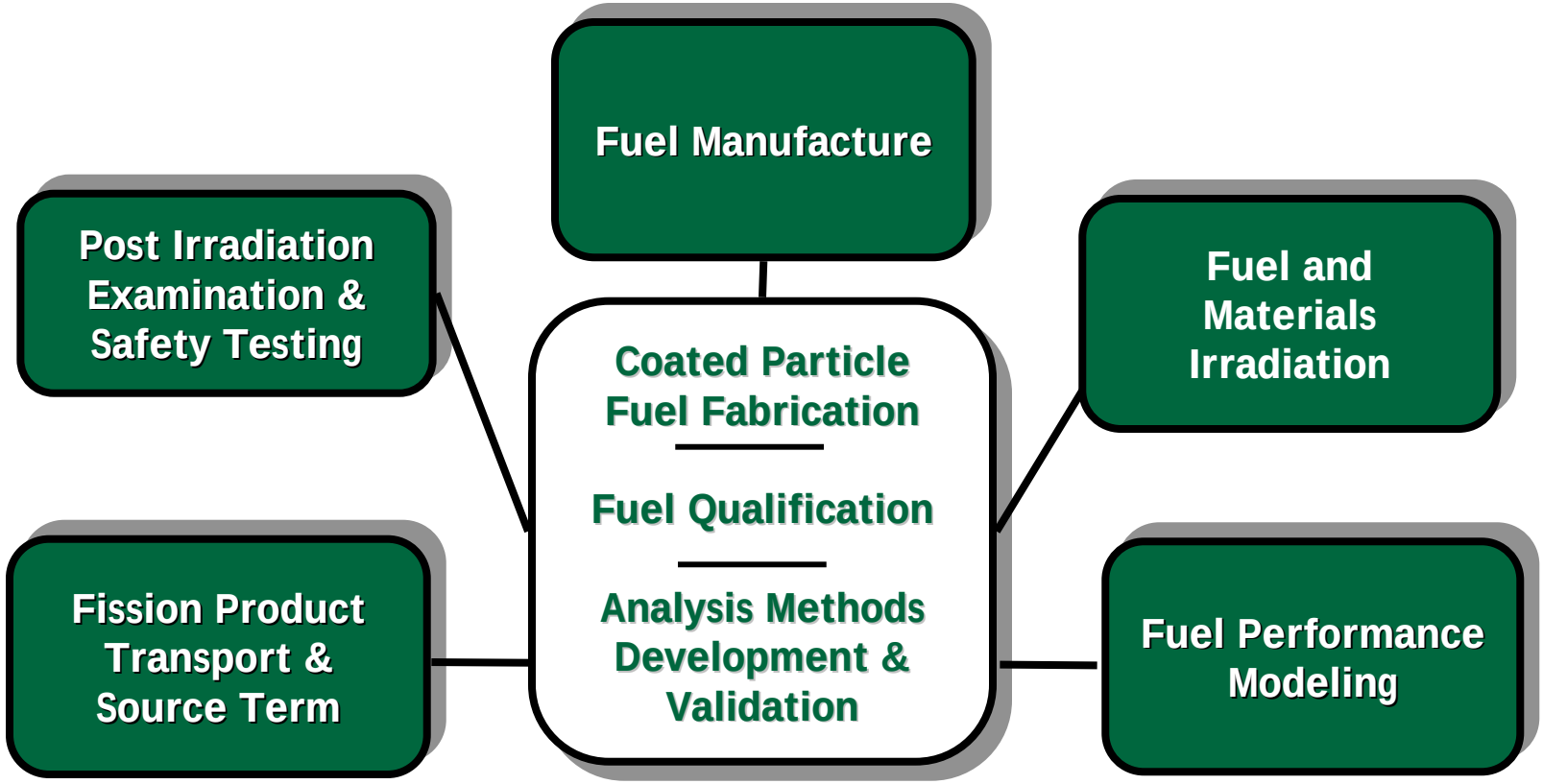
- **Benefits**
  - **Excellent fission product retention**
  - **High Temperature Operation**
  - **Diversion Resistant**
  - **Oxidation Resistant**
  - **Potential for direct disposal**

Fuel is based on reference UCO, SiC, TRISO particles in thermosetting resin (minimum development risk consistent with program objectives)

AGR Fuel Program Approach

- **Build on the US capability and US technology**
  - –**US fuel element and particle designs US fuel and core design codes**
  - –**US fission product codes**
  - –**US annular core design**
  - –**US coated particle fuel testing capabilities**
    - **irradiation capsules**
    - **post-irradiation facilities**
    - **accident simulation tests**
  - –**US engineers and scientists with significant experience in coated particle fuels**
- **Incorporate best German Coating Practices**
  - –**continuous coating**
  - –**PyC coating rate**
  - –**SiC coating conditions**

AGR Fuel Program has several interrelated elements



Program Participants

ORNL, INEEL, BWXT, GA,

Fuel Manufacture

- **Economically manufacture very high quality fuel kernels, particles, and compacts for to provide a fuel manufacturing process specification basis and test articles for fuel testing and qualification.**
  - **Prepare performance specifications**
  - **Manufacture UCO kernels**
  - **Conduct laboratory scale coating process development**
  - **Characterize coatings and compare to German coatings**
  - **Coat fuel test articles in “larger” size coater**
  - **Develop QC methods**
  - **Establish thermosetting resin compacting process**
  - **Address automation and other economies for scaleup**

AGR Fuel and Materials Irradiation

- Total of eight irradiation capsules
  - One to 'shake down' the design and potentially provide early fuel fabrication process feedback data
  - One in support of fuel fabrication process development
  - Two to qualify the reference fuel
  - One for fuel performance model validation
  - Three for fission product transport model development and validation
- Irradiations to be performed at the ATR in Idaho
  - Conditions to be specified based on plant design and licensing requirements
  - Provide in-pile performance data and irradiated fuel and material specimens for examination and further testing

Safety Testing & Post Irradiation Examination

- Conduct safety heatup testing to determine fuel performance under accident conditions
- Perform Post Irradiation Examinations to characterize fission product transport during normal and off-normal conditions.
- Examine any fuel failures encountered
- Characterize irradiated fuel condition
- Examine fuel and material specimens for needed model development data

Fuel Performance Modeling

- Performance models that are more mechanistic are needed to assess candidate particle designs and evaluate source terms for licensing
- The existing coating material property database has large uncertainties
- Additional data are needed to support models for thermochemical and structural/mechanical failure mechanisms
- Additional data are needed to support models for kernel chemistry and carbon monoxide generation
- This fuel development plan identifies the test programs needed to supply the needed data, including outside R&D (e.g., NERI)
- Data to support model development will be obtained under controlled conditions that allow for straightforward correlation of model parameters with temperature, burnup, fluence, and other irradiation parameters
- Independent, integral tests will be performed for validation of models

Fission Product Transport and Source Term

- Take credit for all fission product release barriers - kernels, coatings, graphite, primary coolant pressure boundary, reactor building - in order to meet radionuclide control requirements
- Provide technical basis for source terms under normal and accident conditions to support reactor design and licensing
- Technical basis codified in design methods (computer codes) validated by experimental data
- Suite of computer codes operable on PCs developed under previous DOE programs require model improvement and validation
- Experimental data to be generated by 3 irradiation capsules, PIE, safety testing, out-of-pile loop testing, and in-pile loop testing

Schedule and Costs

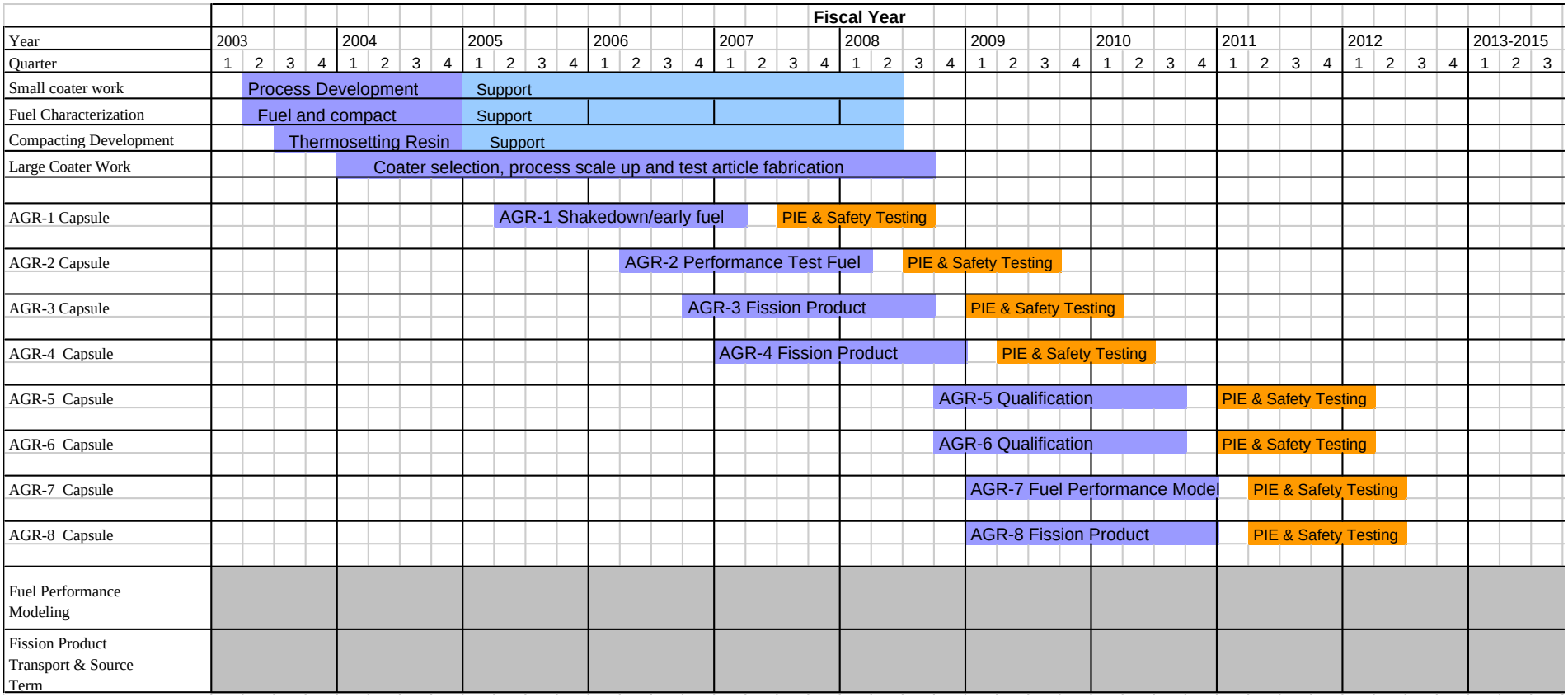
- Program extends through 2012, costs about $ 110 Million
- Qualification tests complete 2010
- Provides feedback in fuel fabrication
- Allows early shakedown capsule tests
- FY 03 and 04 work concentrates on
  - –Fuel Manufacture for reference fuel design
  - – Fuel Kernel Manufacture, Coating technology
  - –First ATR irradiation capsule design: multi-cell capsule
  - –Fuel Specifications

Status

- Program directed from GT-MHR to VHTR Fuel Development and Qualification Program in mid November, 2002
- Program Technical Plan Complete (issued 4/28/03)
- FY03 Implementation Plan, Work Packages Done
- Technical Tasks Underway
  - Coating development
  - Fuel materials characterization
  - Compact development
  - Multi-cell capsule design
- FY04 Implementation Plan development initiated

Advance Gas Reactor Program Schedule Overview

Fully funded program baseline schedule adjusted to begin 03Q2



AGR Program Major Milestones

Fiscal year	Major Milestones
2003	• Complete R&D plan for Advanced Gas-cooled Reactor fuel development and qualification program
2004	• Complete lab scale fuel fabrication studies & begin process scale up • Make kernels
2005	• Begin irradiation shakedown test of new multi-cell capsule (AGR-1)
2006	• Begin irradiation of fuel performance test capsule with fuel variants (AGR-2)
2007	• Begin irradiation of two Fission Product Transport test (materials irradiation) capsules to support licensing (AGR-3, AGR-4)
2008	• Complete post-irradiation examination of shakedown test capsule fuel and material specimens • Begin irradiation of two Fuel Qualification test capsules (AGR-5 & 6)
2009	• Begin irradiation of Fuel Performance Model verification capsule and Fission Product Transport capsule (AGR-7, AGR-8 both support licensing)
2010	• Complete post-irradiation examinations of two Fission Product Transport capsules
2011	• Begin post-irradiation examinations of Fuel Qualification, Fuel Performance and Fission Product Transport capsules
2012	• Complete post-irradiation examination of Fuel Qualification capsules • Complete post-irradiation examination of Fuel Performance Model verification capsule and Fission Product Transport capsule (both support licensing, NRC acceptance)

Summary

- AGR Fuel Development and Qualification Program
  - Early work (FY03, FY04) provides key technical capabilities to support VHTR concept
  - Technology and Science based - provides fundamental understanding of fuel performance
- Overall AGR Fuel Program Technical program plan complete and technical activities initiated
- ORNL lab-scale Coating, Compacting, and Characterization is proceeding with little delay
- INEEL activities initiated for BWXT kernel manufacturing contract and ATR experiment design

Summary

- AGR Fuel Development and Qualification Program is needed to support the Generation IV VHTR Design, and near-term deployment of any gas reactor (NP 2010)
- 'Science' based program --provides better understanding of the link between fuel specifications, fabrication methods, and irradiation and safety performance.
- Provides for multiple feedback loops and improvement based upon early results
- Improves success probability by incorporating German fabrication experience, and U.S. knowledge from previous DOE programs

Backup Slides

Important Progress in FY03 feeds FY04 Activities

- Coating Development, Characterization, and Compacting Technical Plans are complete
- Depleted UO_2 and surrogate kernels to support Coating and Compacting are being made at ORNL
- Non-uranium bearing (surrogate) kernels are being coated to support AGR program and NERI projects
- ORNL Coating Lab for Uranium is operational (surrogates have been coated)
- ORNL characterization lab, equipment is nearly complete
- Final AGR Technical Program Plan has been issued, April 28
- INEEL contract for BWXT to supply UCO kernels and upgrade large scale coating equipment will be issued by 9/03

FY04 focus (according to program plan)

- Complete work to coat TRISO fuel in 2-in coaters (including effort to model the coating process)
- Complete work to establish ORNL basic characterization capability
- Develop compacting process using particle over-coating and thermosetting resins
- Complete design for a multi-cell capsule and begin fabrication
- Begin fuel fabrication scale-up at BWXT
- Investigate promising enhanced characterization techniques
- Consolidate existing phenomenological models into an integrated fuel performance model

Supporting logic underlying FY04 Recommendations

- **Overall Technical Program Plan is technically sound**
  - **Maintains a disciplined approach**
  - **Solid science value and fundamental technology development**
  - **Provides the best path to ensure long term success**
  - **Work the plan, use the plan to establish priority basis**
- **Technical Plan supports the goal of having NRC fuel acceptance target of 2012, for a 2015 VHTR deployment**
- **An ambitious 2012 VHTR deployment necessitates an aggressive AGR fuel program with funding acceleration**
- **FY03-04 funding shortfall is a major issue for a 2015 VHTR deployment**

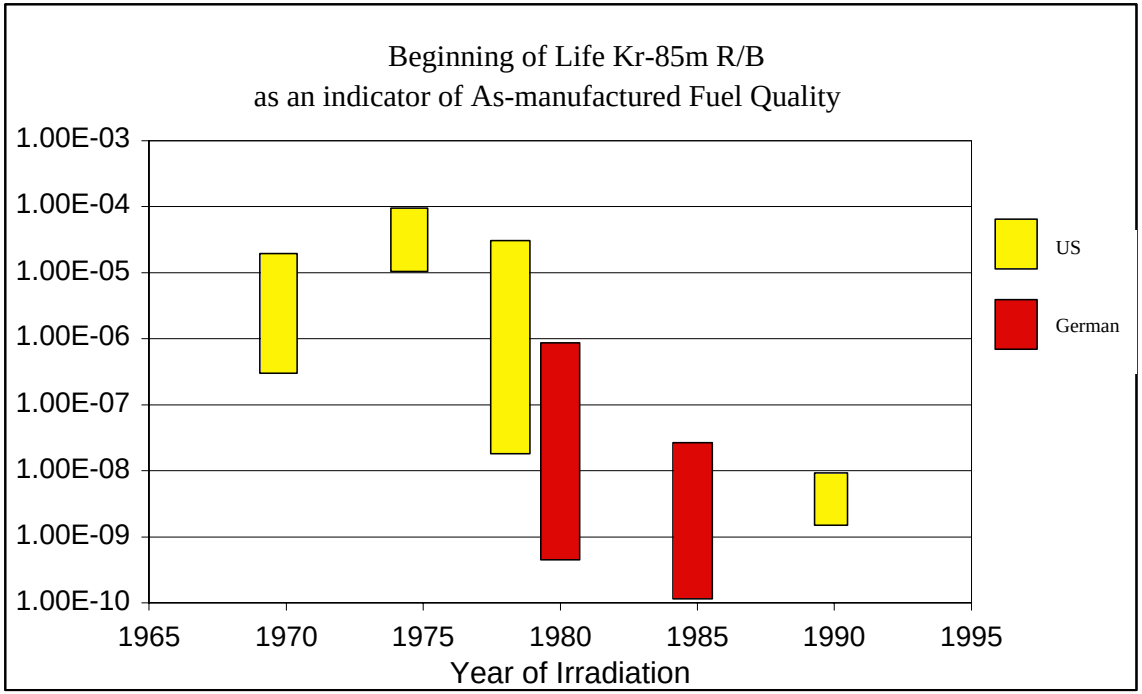
Deliverables in FY04

- Complete work to coat TRISO fuel in 2-in coaters (including effort to model the coating process)
- Complete work to establish ORNL basic characterization capability
- Develop compacting process using particle over-coating and thermosetting resins
- Complete design for a multi-cell capsule
- Begin fuel fabrication scale-up at BWXT
- Begin consolidation of existing phenomenological models into an integrated fuel performance model
- Begin fabrication of multi-cell capsule rig for ATR
- Begin fabrication of irradiation test articles for AGR-1

Deliverables in FY 05

- Complete fabrication of a multi-cell capsule
- Complete compacting process development
- Complete fabrication of irradiation test articles for AGR-1
- Begin irradiation of AGR-1, shakedown capsule tests
- Complete consolidation of existing phenomenological models into an integrated fuel performance model
- Begin to investigate advanced characterization techniques (DELAY most activities into FY06)
- Begin the design of a particle gas analyzer for safety testing (delay fabrication to FY06)
- Design He/Air/Steam ingress safety testing hardware (delay fabrication to FY06)
- Begin initial preparations for PIE

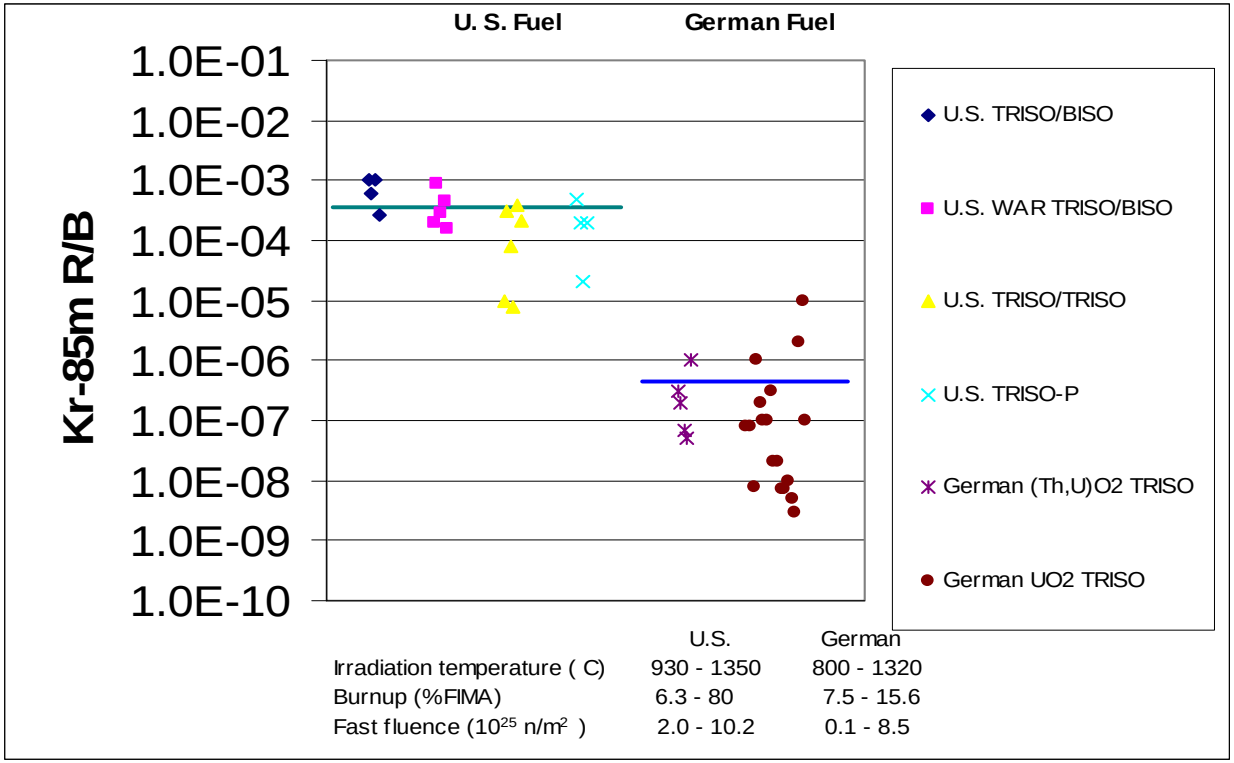
Why Additional Fuel Work is Needed



Comparison of BOL Kr-85m R/B from German and U.S. irradiations.

NP-MHTGR was the first US test fuel with excellent BOL performance

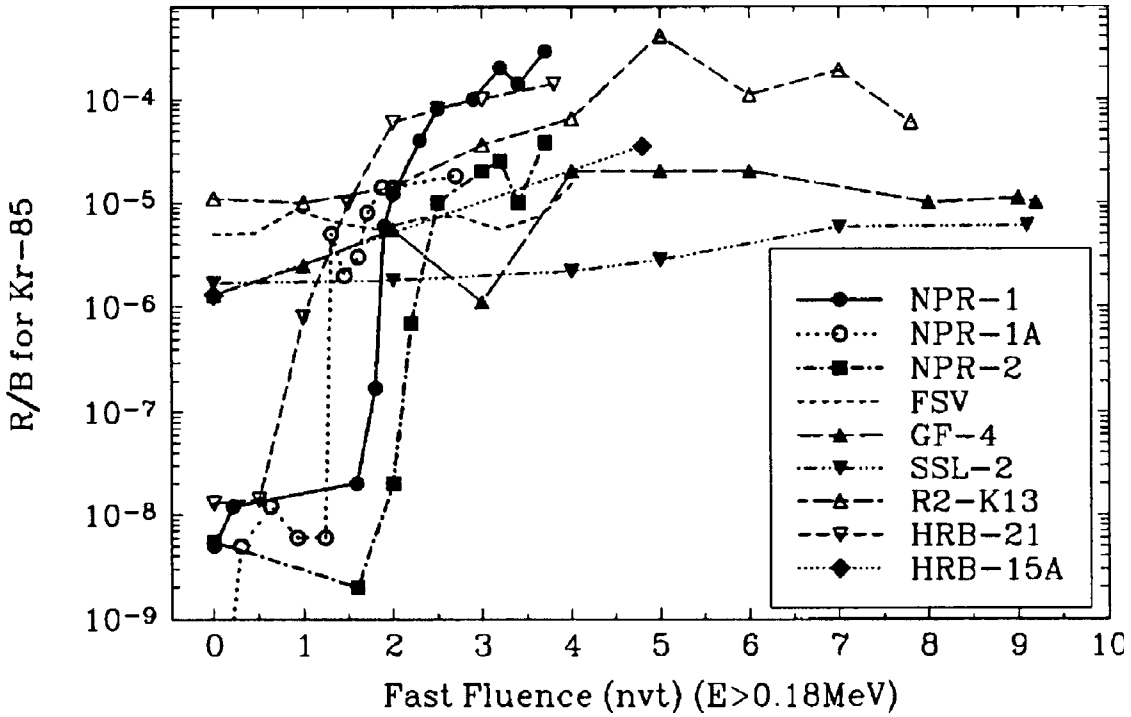
Why Additional Fuel Work is Needed (cont'd.)



Comparison of end-of-life Kr-85m R/B from historic German and U.S. irradiations.

Only German fuel also had excellent EOL performance

Why Additional Fuel Work is Needed (cont'd.)



^{85m}Kr R/B versus fast fluence for various U.S. irradiations.

All US fuel experienced some particle failures under irradiation

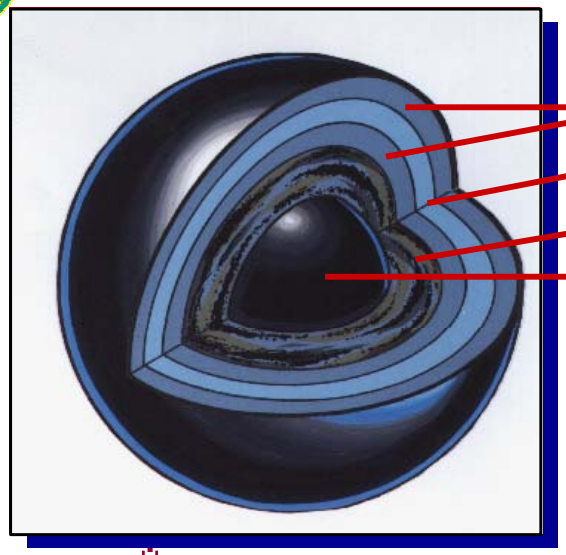
Why Additional Fuel Work is Needed (cont'd)

- US fuel performance has been approximately two orders of magnitude below the level needed to meet plant requirements
- The long lead time required to produce and demonstrate fuel performance make the absence of demonstrated performance a major impediment to strong industrial participation in the deployment of the technology.
- GT-MHR fuel requirements differ from German AVR fuel
  - Different kernel (smaller size, UCO)
  - Higher burnup
  - Higher temperature
  - Greater Fluence

Why Use German Coating Technique?

- German coating technique demonstrated better in-pile performance
- Selection of the German coating technology reduces the fuel program cost because it gives us a starting point for reestablishing, in the US, the technology of coated particle fuel fabrication
- Costs are associated with
  - –establishing a facility for production of test fuel samples and irradiation test facilities which were abandoned during the time of slump in the nuclear industry
  - –cost of performing irradiation, PIE, accident simulation testing
  - –tests to define and validate the fission product source terms
  - –validation of the fuel performance codes
- It will not be straight forward to convert the German process to ours but it is better than starting with a less successful technology

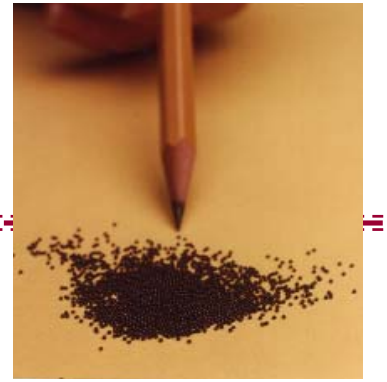
TRISO CERAMIC FUEL



Pyrolytic Carbon
Silicon Carbide
Porous Carbon Buffer
UCO Kernel

GENERAL ATOMICS

TRISO Coated fuel particles (left) are formed into fuel rods (center) and inserted into graphite fuel elements (right).



PARTICLES

COMPACTS

FUEL ELEMENTS